Wireless Visions: Infrastructure, Imagination, and U.S. Spectrum Policy

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ABSTRACT
Effective use of spectrum is essential to the forms of mobile, ubiquitous, and social computing that increasingly shape and define CSCW research. This paper calls attention to the key policy processes by which the future of wireless spectrum – and the forms of technology design and use that depend on it – is being imagined, shaped, and contested. We review CSCW and HCI scholarship arguing for infrastructure and policy as important but neglected sites of CSCW analysis, and separate lines of work arguing for 'sociotechnical imaginaries' as key sites and outcomes of technology policy and design. We then turn to histories of U.S. spectrum regulation, before analyzing ongoing FCC policy actions around incentive auctions and unlicensed spectrum use. We argue that such processes are central to the imagination and future of mobile computing; and that CSCW can benefit from adding such policy concerns to its traditional repertoires of design and use.

Author Keywords
Spectrum; policy; infrastructure; sociotechnical imaginaries; imagination

ACM Classification
K.4.1 Public Policy Issues; K.5.2 Government Issues

INTRODUCTION
In 2010, President Barack Obama issued a memorandum [44] requiring 500 MHz of spectrum – invisible electromagnetic waves that allow wireless devices to transmit and receive signals – to be made available for broadband use, touting the need for "expanded wireless broadband access [that] will trigger the creation of innovative new businesses, provide cost-effective connections in rural areas, increase productivity, improve public safety, and allow for the development of mobile telemedicine, telework, distance learning, and other new applications that will transform Americans' lives." Two years later, Federal Communications Commission (FCC) Chairman Julius Genachowski addressed the same general vision [22], but in more urgent terms: "Just as we must pursue future-oriented energy technologies and policies, we have no choice on our airwaves: we must make better, more efficient use of spectrum…Before long, almost every device we can imagine - from our dishwashers to our cars - will have embedded Internet-connected sensors, and video and other high-data uses will be part of this picture." The alternative, claimed Genachowski, would be dire: "If we don't take the necessary steps, the spectrum crunch will become a spectrum crisis. This would threaten a uniquely powerful opportunity for U.S. innovation and economic growth - wireless broadband - and potentially cede leadership to our global competitors."

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As the above passages make clear, wireless spectrum and the policies that govern it are increasingly central to the visions of broad-scale change and growth that define scholarship and practice in the contemporary social computing environment. As wireless technologies (and the collaborative and social computing applications that run on them) become more pervasive in everyday life, the basic processes by which wireless futures are imagined and enacted through policy become increasingly central to CSCW itself, providing (or failing to) the core infrastructure on which CSCW practice and design efforts rely. Stable, accessible, affordable, and appropriately managed spectrum is increasingly a *sine qua non* of collaborative and social computing systems (or at very least the rapidly growing number of these that operate on a mobile or wireless basis). At the same time, the apparently technical and legal processes of spectrum policy turn out to be social to the core, caught up in the broader cultural (and contested!) processes by which new social computing forms are imagined, practiced, and designed. Contemporary debates around spectrum policy are at once debates about the future of computing, its changing shape and needs, and its broader role and contributions to social life. Current debates in spectrum policy help set the conditions of possibility against which the design, practice, and imagination of emergent collaborative and social computing tools unfolds. They are also shaped by the same broad scale and open-ended (re)imaginations of technology and social life that feed into CSCW work in its moments of research and design.

This paper analyzes core regulatory and policy processes through which new spectrum futures are being built: in law, in code, and in the visions of a networked life that underlie each. It makes three basic contributions to CSCW research. First, it casts light on spectrum infrastructures and policy processes crucial to the success of the field. Traditional CSCW concerns about collaborative tools and practices, and a more recent set of concerns around the shape and nature of mobile and ubiquitous computing, increasingly have to contend with the ways in which wireless technologies interact with – and may be limited by – the spectrum environments in which they live. Second, this paper extends recent CSCW work that seeks to restore policy as a necessary and appropriate site of CSCW analysis. Third, we introduce the concept of sociotechnical imaginaries to cast new light on how social and cultural meanings and visions of the good life may become embedded in technological practices at moments of policy formation. This joins a growing body of CSCW work that has sought to operationalize vision and imagination as a formative influence on the design and cultural appropriation of new computing tools. At the highest level, we argue that wireless infrastructures and the forms of computing design and use which run on them may be deeply if subtly shaped by the policy and regulatory processes that surround them (and vice versa); and that better understanding of such processes can deepen our understanding and potentially help shape the landscape in which CSCW operates.

The paper that follows advances these claims though four basic steps. We first review current literatures around infrastructure and policy in CSCW and introduce the concept of sociotechnical imaginaries. We then turn to the contested history of U.S. spectrum regulation, showing the wider forces and imaginaries that have shaped this regulatory history over time. We then follow two current instances of spectrum controversy – around the proper shape and form of incentive auctions, and unlicensed spectrum use, respectively – revealing the wider processes, visions, and imaginaries they embed. We conclude by discussing key findings around spectrum policy and the work of imagination, and drawing lessons for CSCW practice and scholarship.

RELATED WORK & BACKGROUND

CSCW is undergoing a moment of expansion. Mapping changes in the sites and scales of computing and collaboration itself, recent CSCW scholars have encouraged CSCW researchers to look beyond the moment of design, and above the level of the artifact. Monteiro et al. [33] advocate the study of information infrastructures and the entanglements of seemingly unrelated technologies across multiple times and contexts, arguing that CSCW's tendency to focus on localized system implementation and use neglects a wider and important range of actors and factors in the shaping of a technology. Edwards et al. [13] have urged CSCW and HCI designers to look deeper into the stack of computing, to understand how interfaces, artifacts, and systems sit atop and are profoundly shaped by standards and infrastructures that go typically unaddressed in traditional user-centered design processes. Jackson et al. [26, 27] have urged CSCW researchers to (re)engage technology policy, offering the field's expertise around collaboration and social computing to a growing range of questions and controversies defining public and corporate policies in the collaboration and social computing environment.

Other lines of work have sought to extend CSCW attention to collective processes of imagination, and their role in the design, development, and use of emergent computing forms and tools. This includes work that has approached imagination as a quality or resource of the designer or user. Design artifacts such as prototypes [31], scenarios, and design workbooks [21], represent ways in which designers and developers imagine users, systems, practices, or contexts of use, inscribing notions of the future into the built forms of computational artifacts. Lindtner et al. [32] have examined the role of imagination in the transnational adoption of technologies, and Sengers and Gaver [42] have discussed imagination as a resource for users to interpret design. Still other work has extended the concept of imagination in a cultural direction, exploring how imaginations of ubiquitous computing are embedded, expressed, and reinforced through the actions and products of researchers and practitioners in the field [12] and through sociotechnical visions expressed in the media [23].

But as a largely separate line of work in the STS and science policy space has argued, imagination is no less present or consequential in moments of technology policy formation, including in its technical and regulatory guise. As Jasanoff and Kim [28] explain, sociotechnical imaginaries emerge as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects." These imaginaries represent futures that are both feasible and worthy of collective hope and effort, building projections of "what is good, desirable, and worth attaining" [28]. Building on a wider body of social theory (including seminal work on social imaginaries by political theorist Charles Taylor [43]), sociotechnical imaginaries call attention to the role of the nation state in defining the purposes of technology by tying national visions of culture and identity to concrete policy or funding decisions. They also call out the ways in which science and technology projects and apparently neutral technical decision-making can come to encode, reinforce, or stand in for collective visions of identity or the 'good life' [19, 28].

Sociotechnical imaginaries represent an important addition to other recent approaches to technology policy that have sought to extend understanding beyond simple instrumental and interest-based analyses. Analysts of policy networks [39] have emphasized the fundamentally networked quality of technical decision-making, arguing for the role of interrelated networks, relationships, and linkages among policymaking and other stakeholder communities in creating policies. Analysts of advocacy coalition frameworks [40] have called attention to the ways in which heterogeneous stakeholders interact and coordinate to enact policies. Neo-institutional approaches [20, 36, 37] have explored the role of institutions and wider institutional 'fields' in setting the terrain of policy action, establishing distinct constraints and affordances that draw out certain forms of action and organization while precluding others. Collectively, these approaches speak to the determinants of policymaking, the roles of group ideologies, determining who stakeholders are and how they interact, and the nature of social and power structures. Theories of sociotechnical imaginaries encompass and build on these concerns, while incorporating the role of broader cultural beliefs and values that are not as easily accounted for through network, discourse, or institutional analysis. They also direct attention to the specific instantiations of broad-scale imaginaries within the practices and materialities of technology artifacts themselves.

From the standpoint of the spectrum policy concerns tackled here and CSCW more generally, the concept of sociotechnical imaginaries does important work. Sociotechnical imaginaries allow us to view technological projects and developments within a larger societal context, and analyze their interaction with social life. By reorienting policy as a process of imagination, sociotechnical imaginaries allow CSCW to approach and engage policy in news ways. Sociotechnical imaginaries shape and are shaped by the practices and processes of technology designers and researchers, policymakers, and other policy stakeholders. They show how cultural and social imaginations are mutually constituted with the goals, priorities, and benefits of technology, outlining the extent to which technological choice and form may be caught up in winder, and sometimes contested, cultural and social arrangements.

Spectrum infrastructure is vital to the operation of wireless devices and to emergent forms of mobile and ubiquitous computing. Recent work in CSCW has discussed cases and contexts including mobile health context-aware computing [1], the role of Bluetooth-using sensors or smartphones in crowdsourcing and citizen science [29], ubiquitous sensor networks in urban areas [18], and new forms of high-bandwidth-using communication such as collaborative live video [14]. Currently contested FCC decisions will set the stage for new designs and practices related to wireless technologies. The choice of what spectrum frequencies to allocate for internet access affects whether signals can penetrate through buildings in urban areas, or transmit across long distances in rural areas, influencing the development of mobile and geolocation based systems. The way in which frequencies are allocated can enable (or prevent) the adoption of higher bandwidth Wi-Fi standards. Spectrum usage rules may create restrictions on wireless transmissions indoors, near hospitals, or in other locations. Debates over spectrum regulatory regimes often translate into a choice between increasing capacity of cellular networks, or Wi-Fi and Bluetooth networks, affecting what types of mobile devices and sensors can be used in an area. These regulatory regimes are also associated with competing views between limited and open access to technological systems. Cultural meanings of technology are not just influenced by the imaginations of designers and users, but also by the imaginations expressed (explicitly or implicitly) through regulations, proposals, and other processes of policymaking.

Investigating spectrum extends CSCW analysis both practically and theoretically. Practically, spectrum infrastructure is crucial to the wireless systems on which CSCW increasingly relies. Theoretically, our analysis extends work understanding how broader cultural processes affect the imagination, practice, and design of technology, particularly contributing to a growing body of CSCW work that attends to the policy processes and conditions around technological development. The following sections apply these concepts to problems of contemporary U.S. spectrum policy. We begin by reviewing historical and contemporary technological and policy developments and debates in spectrum. We then explain and analyze two contemporary spectrum debates – around license auctions and unlicensed spectrum, respectively – before turning to a discussion of the significance of spectrum policy and sociotechnical imaginaries for CSCW research more generally.

CONTESTING SPECTRUM: HISTORY AND CONTEMPORARY DEVELOPMENTS

Over the past century of radio spectrum history in the United States, shifts in basic understandings and practices around electromagnetic spectrum parallel considerable technological, regulatory, and social change. Spectrum has long been historically contested, and conflicting social visions and imaginations have always been at the heart of the core policy processes that govern it. This contestation is particularly prominent in policy debates in response to (and in anticipation of) emerging wireless technologies, representing the working out of new sociotechnical imaginaries. Understanding the historical policy responses to emerging technologies and the contexts for those responses can help us understand the policy concerns that shape contemporary forms of computing and communication. Both historical and current technical and policy debates have significant cultural dimensions that are wrapped up in broader social visions.

This constitutive principle can be witnessed at multiple moments of wireless policy history. When wireless radio was introduced to the U.S. in 1899, three groups fought to be the main users of radio, each representing a different vision about the future of radio and who would control it [11]. The press framed radio as a way to disseminate news to the public at faster speeds and lower prices than the telegraph or telephone. The Navy considered military or government promotion and control of radio as a sign of international prestige and strength. Hobbyists envisioned radio belonging to "the people," where individuals would communicate with each other through amateur clubs. The Radio Act of 1912 responded to increasing spectrum congestion and addressed the question "Who has the right to transmit?" [11]. Congress felt that government stewardship over spectrum would best serve "the people," while they felt that hobbyists created wasteful and dangerous interference. Subsequent actions established private corporations and commercial broadcasters as the main stakeholders and users of radio, diminishing the role of amateur users. The 1912 Act established a centralized government licensing system, later incorporated into the Federal Communications Commission (FCC) in 1927, whose impact is still felt, as today, much of the spectrum is licensed to private corporations and commercial entities. The FCC continues to allocate spectrum for various uses, determining the size of bands and the technical rules of use, and assigns those allocations to users through a variety of licensing regimes.

The emergence of wireless television in the 1940's shows a similar story of conflicting sociotechnical visions [25]. Radio companies heavily invested in developing television technology, so their previous ideals of a commercially supported network-based broadcast system translated from radio to television. However, the FCC envisioned local broadcasters, not national networks, as the center of the broadcast system, believing that local broadcasters would respond to local community needs, create diversity, and represent the "public good." In 1941 the FCC began television service but authorized commercial operation to allow operators to recoup development costs. The FCC distributed television spectrum licenses equally across the nation by geographic area to implement their vision of local broadcasters. But because it was based on geography, not population, most stations did not have the economies of scale that network television stations would have, and could not support themselves in the commercial system. This system allowed the rise of the three network oligopoly, reinforcing the commercial vision of broadcasting.

The broadcast reform movement of the 1960's [24], occurring simultaneously as other activist movements in American civil society, was largely concerned about broadening the range of actors involved in spectrum debates and changing the conception of "the public good." Prior to the 1960's, there was no way for citizens to publicly challenge broadcast licenses, as predominantly only other licensees had legal standing before the FCC. Broadcasters had a narrow view of what constituted legitimate actors, arguing that the public interest was already represented by the FCC. Reform groups believed that the FCC alone was not sufficient in protecting and promoting the public interest. Tensions surrounding who should be allowed to have a voice in these debates came to the surface in the 1966 case *Office of Communication of the United Church of Christ v. FCC*, which ruled in favor of the reformers, expanding the definition of who has legal standing to argue before the FCC, allowing citizens to challenge the licensing of commercial stations, and widening the number of legitimate stakeholders involved in spectrum.

Contemporary approaches to spectrum build from this technical and regulatory history and tend to follow either a policy- or technology- centered path. Policy-centered approaches seek to reform the mechanisms by which spectrum is awarded and used, encouraging efficient, optimal, and high-value uses, and generally fall into one of three approaches. First, advocates of market-based licensed approaches have argued for salable property or quasi-property rights as a way of ensuring efficient spectrum distribution, and looked towards market mechanisms like auctions as means of awarding new spectrum made available through redistribution. A property-like license grants a licensee exclusive use of certain frequencies in a particular geographic area. Second, others argue for commons-based unlicensed approaches, analogizing spectrum as a common resource, allowing anyone following a few basic operating rules to access and use the spectrum without purchasing a license. This would lower barriers to entry and allow more users to access the same frequencies of spectrum. While these two policy approaches have existed in some form for decades, a growing third group broadly proposes creating spectrum "sharing" environments [38] in response to the spectrum crunch, as most spectrum has already been allocated and assigned; there is no "new" spectrum to be found. Sharing environments have primary and secondary users: the primary user has greater protection rights from interference while secondary users can use the same frequencies as long as they do not interfere with the primary users. However, questions persist [35] as to how the primary and secondary users should be regulated.

Technology-centered approaches tend to make more efficient and "opportunistic uses" [15] of spectrum by helping devices transmit on frequencies otherwise not being used in a certain location at a particular time. One such solution is white space databases, first tested in 2008. White space is spectrum that has been allocated for a use, but is not being used or is unassigned in a specific geographic location. This spectrum can be used for other purposes without impact on the primary user. The databases provide centralized management and organization, communicating with devices to see where, when, and on what frequencies it is safe to transmit without interfering with primary users. Cognitive radio is similar. A cognitive device can itself sense if other devices are transmitting on the same frequency and in the same location, determining when it is opportune to transmit signals. With dynamic frequency selection technology, cognitive radios can sense several frequencies for primary users, and reallocate signals accordingly. Both white space databases and cognitive radio work well with unlicensed and spectrum sharing policies, more easily allowing users to transmit on multiple frequencies in crowded environments.

Outcomes of regulatory debates directly affect technology design and use (including the social computing tools and practices regularly studied by CSCW researchers). Cellular internet services are built on licensed spectrum because cellular carriers can afford to pay for licenses. Wi-Fi networks and Bluetooth technologies were developed and operate on unlicensed spectrum, in part due to the openness and lower barriers to entry in the unlicensed environment. The choice to regulate a band of spectrum as licensed or unlicensed affects how users can access spectrum reliant services, such as what types of wireless devices they have to purchase or organizations they may have to work with in order to access spectrum, like mobile phone companies. The geographic availability of both licensed and unlicensed spectrum also affects where and how users can use internet-connected devices. Furthermore, there is also debate as to whether or not more spectrum should be devoted to wireless broadband versus other uses like emergency communication networks or local television stations. Spectrum management technologies that allow sharing environments often envision a non-internet service like radar communication as the primary user and internet service as the secondary user, whether licensed cellular or unlicensed Wi-Fi based. Other views of sharing environments envision the primary user as licensed cellular service and the secondary user as unlicensed Wi-Fi service.

This brief overview of U.S. spectrum policy reveals several notable features. One of these concerns the deep interweaving (or 'knots' [26]) which connect design, practice, and policy over time. This is particularly visible during the emergence of new technologies and regulations, such as television. Over time, the uses of spectrum have grown, from radio broadcasting to television, cellular phones, Wi-Fi, Bluetooth, and more. Correspondingly, the class of claimants on spectrum spaces has grown, incorporating a new class of engineers, businesses, designers, and users creating, deploying, or adopting these technologies. Although conceptions of the "user" in spectrum policy often differs from CSCW conceptions of the user – users are generally considered in broader terms such as consumers, viewers, or the general public – the way that users are envisioned by policymakers expresses a social vision associated with the technologies. Spectrum debates around technical standards and regulations are wrapped up in broader social visions regarding the public good and the role of wireless technologies in society. Whether through institutional, political, or economic muscle, incumbent stakeholders have often played a large (some would say too large) role in defining and sometimes limiting spectrum debates. Concurrently, spectrum debates are embedded in broader shifts in regulatory and political philosophy, such as social reform movements in the 1960's. Imagination has been a force through which spectrum debates and controversies take form and are managed. These imagined visions have shifted over time, but are of fundamental importance to spectrum debate. Imagination is both social and technical, envisioning particular users, uses of spectrum, and views of the "public good," as well as envisioning future devices, systems, and standards.

The sections that follow extend this analysis by considering two pending policy actions in the spectrum space. The first concerns the introduction of a policy tool called an 'incentive auction' in order to expand licensed spectrum use for broadband but also asks how licensed users might share spectrum with unlicensed secondary users. The second describes the expansion of unlicensed spectrum for broadband and also raises concerns about incumbent services located in the same bands. These two policy and technical debates are also implicitly debates over the cultural dimensions and social visions of spectrum. We then turn to a more general discussion of patterns and tensions in contemporary spectrum policy and their implications for CSCW research.

CONTEMPORARY SPECTRUM DEBATES

The FCC Incentive Auction

While the FCC has used auctions to assign spectrum since 1993, the idea of an "incentive auction" was first described in the 2010 National Broadband Plan. In 2012, the FCC proposed rules [16] for an incentive auction to reallocate television spectrum for internet usage, consisting of three parts. The first part is a reverse auction, allowing broadcast television licensees in the 600 MHz range to submit bids to relinquish spectrum in exchange for payments, funded by the later forward auction of new licenses. The second part is a repacking of the newly obtained spectrum for wireless internet, and creating the new rules of use for these bands. The last part is the forward auction of new licenses for wireless internet uses, mostly to telecommunications companies to expand cellular networks. A successful auction requires the interplay between all three components.

Most stakeholders tend to fall into one of three competing groups: those who want to increase licensed spectrum for internet via cellular networks such as telecommunications companies, those who want to increase unlicensed spectrum for internet via Wi-Fi such as software companies and Wi-Fi device manufacturers, and incumbent low-power broadcasters who want to preserve spectrum for low-power television broadcasting. The FCC proposes repacking the 600 MHz band into 5 MHz blocks. They envision the use of Frequency Division Duplex (FDD) standards, such as 3G and 4G network standards, as FDD standards require a pair of 5 MHz blocks, one for uplink signals, and one for downlink signals [9]. The FCC also proposes creating guard bands (unassigned frequencies to help prevent interference) to protect continuing TV channels from interference. The FCC's plan is shown in Figure 1. It may be possible to instead use the guard band frequencies for unlicensed uses, by using white spaces databases or cognitive radio to make sure that their signals do not interfere with licensed operators. The FCC frames this proposal by linking it to

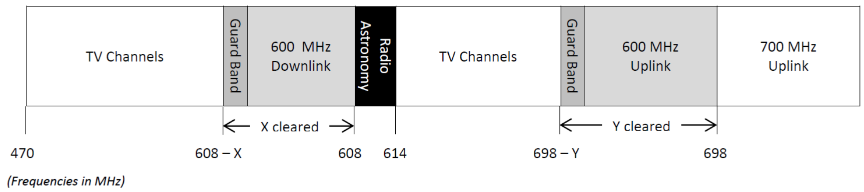

Figure 1. A possible band plan of the 600 MHz band as proposed by the FCC [16]. The areas "X cleared" and "Y cleared" are proposed to be auctioned off in 5 MHz block licenses. The variables X and Y indicate that the FCC is not yet sure how much TV spectrum will be cleared in the reverse auction. The appropriate size for the guard bands is currently contested.

economic growth and a narrative of American exceptionalism, saying "Meeting this [spectrum shortage] challenge is essential to continuing U.S. leadership in technological innovation, growing our economy, and maintaining our global competitiveness" [16].

At the heart of this debate is the form and nature of the public good, seen through contestation over the appropriate form and mechanism of efficiency, concerns about public access and competition, and beliefs about the reliability of new technologies. Regarding the most efficient use of spectrum, licensed regime supporters advocate shrinking guard band sizes to free more spectrum for licensed auctions, stating that these bands are "prime spectrum for the provision of mobile broadband services, so the guard bands should be limited in size to what is necessary to mitigate harmful interference, rather than attempting to maximize unlicensed spectrum use" [6]. Unlicensed spectrum advocates cite the potential for transformative innovations in unlicensed spectrum such as Wi-Fi and Bluetooth, and argue for larger guard band sizes to support unlicensed devices operating on wider band white space standards. They also cite the economic efficiency of unlicensed spectrum as "a complement and cost saving to both commercial wireless carriers and to wireline ISPs" [9]. Technical arguments about efficiency represent broader cultural claims about the relative importance and envisioned future roles of cellular and Wi-Fi based services.

Furthermore, some groups argue for using Time Division Duplex (TDD) standards instead of FDD, which requires a different, simpler organization of uplink and downlink bands. TDD could also benefit newer market entrants or those with fewer spectrum holdings like Sprint, while FDD is likely to benefit current operators such as AT&T and Verizon, who already have existing FDD infrastructure. Arguments for TDD are also based in certain hopes and representations of TDD standards and technologies. Referring to TDD as the "global solution for unpaired spectrum," and citing its use by other countries [10], Sprint frames TDD as the standard of the future. Yet FDD is embedded into current policies, regulations, and technological device designs. These debates help explain why a standard that may be the most efficient in one aspect, such as the technically efficient TDD, may not be adopted. Many groups associate the public good with the most efficient use of spectrum (even considering the difficulty of defining efficiency). But others associate the public good with other qualities, such as increasing public access to broadband internet connections through Wi-Fi, maintaining public access to television, or creating a more competitive environment for wireless carriers. Eventual regulatory choices in the 600 MHz band will embrace certain definitions and visions of the public good and efficiency at the expense of other competing definitions, embedding those values in the wireless infrastructure.

Contestation occurs over meanings of new spectrum management technologies that allow unlicensed devices to share spectrum with licensed devices, like white spaces databases or cognitive radios and their associated standards. Fears about their reliability are raised as opponents state [4] that band sizes "should be sized consistent with today's filter technology, not for future, aspirational technologies." Implicitly, this is a fear of an expanded unlicensed spectrum environment exploding with multitudes of new wireless devices. Supporters portray the these technologies as safe and tested, citing the FCC's resources devoted to white spaces deployment, including "testing and approving database administrators for commercial use, and certifying white spaces equipment" [5]. This debate is reflected in the development of regulatory rules for these bands which will favor the use of certain technological systems over others, implicitly favoring their associated values and narratives.

The physical properties of the 600 MHz band easily allow the transmission of information across long distances, making it valuable for deploying large wireless networks in open areas. The auctioning of 600 MHz spectrum provides the opportunity to greatly increase the capacity of wireless broadband networks, whether based on licensed spectrum for mobile broadband, or unlicensed spectrum for Wi-Fi. This is also likely the last auction of spectrum in this range for the foreseeable future, raising the stakes of these debates as there may be few future chances to change the rules and organization of this band once a proposal is adopted.

A number of more general features stand out in this debate. First, there are different conceptions of which stakeholders are legitimate and which should hold more influence, particularly between cellular network supporters and Wi-Fi supporters, while both tend to marginalize the role of low-power television broadcasters. Second, users are broadly conceived of as consumers who need more broadband access to accommodate higher bandwidth-using services and a greater ubiquity of wireless devices, though how broadband will be accessed (via cellular networks or Wi-Fi) is contested. Third, defining the "public interest" is contested, with different implications for what type of technical and regulatory environments would best serve that public interest. Fourth, current debates about the 600 MHz broadcast spectrum build upon past actions, technologies, and regulations, such as the legacy of the broadcast TV system, and the embeddedness of prior standards such as FDD. Lastly, this case is placed within a larger debate over how to best manage spectrum, mostly contested between unlicensed and licensed management regimes. Any lasting solution will not be purely one or the other, but will combine both management regimes. However, questions still exist regarding the extent to which they should coexist, and if one management regime should be valued more than the other. These technical and regulatory debates are also debates about what types of sociotechnical futures we will enact and what cultural values we will promote.

Expanding Unlicensed Spectrum

In February 2013, the FCC issued an NPRM regarding "Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band" [17]. The FCC intended to revisit the rules governing unlicensed devices in the 5 GHz bands, which were written in 1997. Part 15 Rules govern the operation of unlicensed devices: wireless devices can operate without obtaining licenses as long as they follow rules intended to prevent interference for licensed devices operating within and adjacent to U-NII bands. Thus unlicensed devices are generally required to operate at low power over relatively short distances. Wi-Fi devices are an example of an application operating under these rules. Currently, there are several U-NII bands, seen in Figure 2, each with different operating rules.

The rules of existing U-NII bands vary. While they all allow for the operation of unlicensed devices, some have different restrictions on indoor and outdoor usage, different power limits, and different rules about what measures unlicensed devices need to take in order to avoid interference with legacy licensed services like radar or satellite communications. One section is governed by Part 15.247 and U-NII-3 rules, where manufacturers can decide which of these rules make more sense for them when building devices. The FCC proposes to expand U-NII rules into two new bands, designated U-NII-2B and U-NII-4, increasing the amount of contiguous U-NII spectrum.

Expanding U-NII carries potential issues. Incumbent services in the U-NII-2B and U-NII-4 bands include satellite services, weather radar, services used by local TV stations to provide weather warnings to viewers, and Dedicated Short Range Communications Service (DSRC) systems. DSRC is for automobile safety systems, such as vehicle-to-vehicle wireless communications that may warn drivers of impending dangerous conditions, or help make the vehicle take evasive action. These incumbent users operate within a licensed regulatory regime. Some form of spectrum sharing and mitigation of interference between licensed incumbent users and unlicensed U-NII devices in these bands is proposed to protect incumbent services.

The main opportunity of unifying the U-NII rules is the possible adoption of the IEEE 802.11ac Wi-Fi standard, which uses wider bandwidth, up to 160 MHz, for up to 1 Gigabit per second services. However, each of the U-NII bands has different policies of use, so if the 160 MHz-wide Wi-Fi channel was spread across two or more U-NII bands, it could fall under multiple sets of operating rules. Reconciling differences like power or location limits would create larger swaths of contiguous spectrum regulated in the same way allowing multiple 160 MHz-wide channels.

The FCC also identifies an increase in U-NII interference incidents "caused by users unlawfully modifying and operating unlicensed devices that have not been certified" [17]. Many manufacturers create devices that can work all the U-NII bands, but use software to operate on a specific band. If users edit the software, they may cause a device to operate in bands where the device causes harmful interference. The proposal envisions users as consumers whose interaction these devices does not include editing device software.

Central to this debate are varying portrayals and perceptions of stability, risks, and benefits of spectrum sharing management technologies. The push to increase unlicensed spectrum in the U-NII-2B and -4 bands is in part predicated on the development and trust of new technologies such as dynamic frequency selection and geolocation databases that allow spectrum sharing between new unlicensed devices and prior licensed incumbent devices. DSRC and Doppler licensees argue that these new tools are risky and pose potential threats to public safety if interference occurs. This represents a fear of a broadened unlicensed spectrum environment exploding with new wireless devices. While it is generally agreed that incumbents deserve protection from interference, there is debate over how much interference constitutes *harmful* interference and how well new technologies can mitigate that interference. Automobile manufacturers of DSRC devices and Doppler radar operators argue that their services protect public safety, writing "DSRC holds great promise for saving lives…these

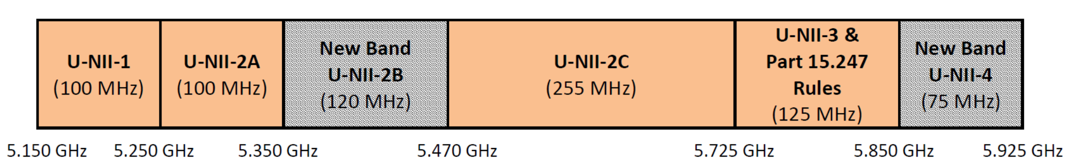

Figure 2. Current U-NII Bands and new bands proposed by the FCC in the NPRM [17].

enhanced safety features contain stringent communication requirements that must be protected" [3] and that "accurate weather data that can be rapidly delivered to local communities is a critical public safety priority" [8]. Thus they argue that they should have greater and preferential access to spectrum, priority to transmit, and greater levels of protection from interference from unlicensed devices.

The values of economic growth and innovation underlie most stakeholders' arguments: effective spectrum management is seen as a way to grow the U.S. economy and promote technological innovation. The FCC states that these changes "would continue to foster the development of new and innovative unlicensed devices, and increase wireless broadband access and investment" [17]. Yet the value of economic growth can be interpreted in conflicting ways. Unlicensed spectrum and Wi-Fi advocates argue that access to a harmonized unlicensed spectrum presents an environment with low barriers and easier access to entry, promoting innovation and meeting growing consumer demand. They envision a future of more unlicensed devices with more uses, writing "A more unified and streamlined regulatory structure will…promote the growth of the U-NII market…Technologies will have myriad uses that are vastly different from what reasonably could have been predicted when the U-NII-1 rules were first adopted in 1997" [7]. Meanwhile, incumbent licensed users argue that more unlicensed devices will present unknown factors, decreasing the spectrum's value; guarantees of stability and interference protection are needed for companies to invest money into building and innovating new technologies.

The debates in this case exhibit several general features as well. First, questions and contentions once again exist about who the legitimate stakeholders in creating spectrum policy are, and how much influence they should have. This is seen in disagreements between Wi-Fi advocates (including Wi-Fi and spectrum sharing device manufacturers, public interest groups, and software and internet companies) and incumbent spectrum users. Second, users are envisioned in several ways. Unlicensed spectrum advocates envision users as consumers who will use mobile internet services that require more data and content to be sent faster among more devices. The FCC and many manufacturers envision users as consumers of content who should not directly interact with device software. Third, the public interest is alluded to by many of the commenters, if not directly described. One view equates the public interest with the consumer's interest – the benefits of competition, lower prices, and marketplace innovation stem from an unlicensed spectrum regime. Another view is centered on public safety: widespread adoption of services that protect public safety during disasters or prevent disasters is vital to the public interest. Yet another view envisions expanding broadband connectivity via Wi-Fi as the public interest. Fourth, the FCC is operating in the context of legacy incumbent operators and devices built for the existing U-NII regulatory environment. Lastly, these debates are exploring how the regulatory environment can support the possibility of mutual coexistence of licensed-, unlicensed-, and sharing-based spectrum management regimes. Working out the technical and regulatory coexistence of these regimes relies on sorting out and ultimately embracing certain sociotechnical visions and cultural values.

DISCUSSION

This paper has sought to reveal the complexities and intricacies of spectrum debates, in both their historical and contemporary variants. It has introduced the concept of sociotechnical imaginaries as a way of understanding the mutual relationships between policy and technology design and practice. It has demonstrated the deep contestation of spectrum and the role of imagination in spectrum debates, both historically and in two contemporary cases that address the spectrum crunch. Here we discuss the importance of new attention to spectrum infrastructure and spectrum policy, supplementing CSCW's traditional orientations towards design and practice at the level of individual artifacts and systems.

Evaluating U.S. spectrum policies reveals several dimensions of sociotechnical imaginaries that emerge repeatedly over the history and contemporary practice of policy making around spectrum. The first concerns the debate over which actors should be allowed to participate in spectrum debates, both in terms of which groups' imaginaries are deemed legitimate and in terms of what groups are envisioned as legitimate policy actors. The second dimension is a contested imagined view of who the *users* of spectrum are (which are not always the same as the answer to question one). The third dimension consists of the debated definition and interpretation of the "public interest" at the heart of spectrum debates. The fourth dimension is that sociotechnical imaginaries are shaped by prior and existing technologies and regulations. They are built upon and constrained by the technical, regulatory, and cultural legacies of the past. The last dimension reveals the direct and real consequences sociotechnical imaginaries have on immediate questions surrounding spectrum management policies and techniques. Imaginaries are not merely theoretical, but affect real policy debates and actions.

Sociotechnical imaginaries reframe policy as imaginative and cultural processes. Using this to understand and engage policy and infrastructure, especially spectrum, can contribute to CSCW scholarship in three ways: understanding how infrastructures imagine and shape social and technological development, presenting a policy-centered resource for design, and analyzing how imagined futures and cultural values are mutually reflected and embedded in both technology and policy.

First, spectrum infrastructure, standards, and the regulations that govern them deeply influence the practice and design of wireless technologies built upon the infrastructure. At a deeper level, sociotechnical imaginaries help imagine and create future social and technological worlds and environments in which CSCW operates in. The resolution of current spectrum debates will shape the environment in which wireless devices will operate in. In the incentive auction case, the dominance of cellular or Wi-Fi based internet services will affect the types of technologies CSCW researchers can study, design, or implement, such as the ability to use mobile sensors or smartphone services. In the U-NII case, adoption of the 802.11ac Wi-Fi standard could increase the locations and contexts in which users use video and other high-bandwidth forms of communication. Constraints on power or indoor usage affect the locations and ways that wireless devices and sensors can be designed and deployed. Limits on unlicensed spectrum near legacy licensed users such as DSRC vehicles or radar stations could affect the design and use of mobile and location-based systems. Debate over legitimate stakeholders, legitimate users, and legitimate user actions can affect how users access and interact with spectrum-using devices, such as the ability or inability to edit device software. Current spectrum debates represent the emergence of new technological and regulatory opportunities, sparking contestation and debate. These debates will eventually stabilize and coalesce around a new sociotechnical imaginary around spectrum embracing certain sociotechnical visions.

Second, sociotechnical imaginaries provide a policy-centered resource for design to create and explore imagined futures of technologies, society, and configurations of users. Used to supplement traditional user-centered design, policy-centered analysis and design can contribute alternative views of users and provide insight into social values and sociotechnical infrastructures underlying current design and practice. A focus on policy broadens the design space by considering design opportunities presented (or inhibited) by alternate policies and infrastructures. How would a wireless device or service be designed if wireless broadband was only offered via cellular providers, or only via Wi-Fi? How would users interact with sensors that could only be used indoors, or only outdoors? Furthermore, understanding the debate and contention around spectrum policy and regulation can help us understand gaps that users may face, such as differences between indoor and outdoor operation of devices, switching between cellular and Wi-Fi networks, or the limits of wireless device use in sensitive locations such as near vehicle safety systems. These understandings of policy can be leveraged as a resource by designers and practitioners for seamful design [2, 42**]**, allowing users to be aware of, interpret, and engage the uncertainties and conflicts present in wireless policies and infrastructure. CSCW can likewise contribute to the policy domain. In particular, there is space for CSCW to contribute an understanding containing more concrete notions of users and designers that have been largely missing from policy debates. This can be done through direct engagement with the policy making process or by shaping these notions through processes of imagination, building narratives through conversation, publication, and design.

Third, as an analytic tool for CSCW, sociotechnical imaginaries help us understand how broader cultural beliefs and visions become embedded and reflected in policies, regulations, sociotechnical systems, and technical artifacts. Values in Design work in the CSCW and CHI communities has investigated the human values promoted by or embedded in technologies. Some work has also investigated connections between values and broader cultural dynamics and norms. Sociotechnical imaginaries and the policy processes that in part frame them are a key mechanism by which values get built into the systems and infrastructures that CSCW relies on. The licensed versus unlicensed regulatory debate in the incentive auction weighs the values of closed versus open access, mirroring questions about closed and open technological systems. Conflicting notions of the public good in the U-NII case debate what values are deemed legitimate: broadening internet access and speed, increasing economic growth, or protecting public safety. Understanding these dynamics opens a space for researchers and designers to investigate how the values embedded in or promoted by technologies interact with the values and norms expressed through policymaking processes. By placing these broader processes and institutions, including policy, as a central part of CSCW analysis, we are better able to move beyond statements of technological or social causality and investigate sites of mutual sociotechnical shaping that may have long-term effects on the nature, shape, and impact of CSCW and social computing tools and practices.

Some of this sociotechnical shaping occurs at the level of metaphor. Metaphors, such as those underlying spectrum policy and technology policy, contain implicit cultural assumptions. Metaphors also provide tangible ways to describe invisible spectrum and provide common terminology for a wide variety of stakeholders [34]. Land is often used as a spectrum metaphor. In the land metaphor, licensed spectrum is analogized as private property, while unlicensed spectrum is represented as a commons. However, land-based metaphors imply one regulatory regime per one section of spectrum; spectrum sharing regimes do not translate well in this metaphor. The land metaphor also tends to focus on policy-centered solutions over technology-centered solutions. Despite their shortcomings, metaphors are cognitive constructs that help shape human thought and reasoning [30]. These metaphors become so deeply embedded that they become "real" and assumed true, shaping our expectations and outlook of spectrum along technical, social, and regulatory dimensions. Attention to sociotechnical imaginaries helps us reveal, understand, and question these assumptions. Making metaphors visible through sociotechnical imaginaries allows us to better understand social values and assumptions in the design space by embracing, questioning, or inverting dominant metaphors, similar to critical and reflective design techniques [41]. Harmon and Mazmanian [23] discuss how cultural meanings of personal technologies are affected by cultural narratives in advertisements and news articles. Similarly, policy has the ability to shape technologies' cultural meanings through metaphor. Metaphors can be shaped and changed, however, providing an opportunity for CSCW to leverage its knowledge and experience by helping to form or contest the underlying metaphors that shape the sociotechnical imaginaries involved in policymaking. Conversations, publications, and design work are ways to engage in creating cultural meanings [23]. Through processes of imagination, CSCW researchers and practitioners can affect metaphors and narratives about wireless technologies.

CONCLUSION

At the time of writing, spectrum policy in the U.S remains fundamentally unsettled. As regulators try to allocate more spectrum for cellular broadband networks and/or unlicensed use, opportunities and risks for new and incumbent stakeholders are growing. In both cases, technical questions regarding standards and band sizes are linked with social questions regarding access and legitimate stakeholders. Competing definitions of efficiency and the public good, perceptions of benefits and risk of new technologies, and broader sociotechnical values and priorities must be negotiated. These debates are framed against the backdrop of the uncertainties posed by a looming spectrum crunch, which threatens an imagined future of Americans leveraging ubiquitous wireless broadband for innovation, health care, media content, social interaction, and many of the other claims and visions around the future of ubiquitous and mobile forms of computing.

Within this unsettled environment, attention to the sociotechnical imaginaries that frame and construct such debates is crucial. Sociotechnical imaginaries provide a tool for analyzing technology policies and can be leveraged as a resource and inspiration for design. They embed visions of stakeholders, users, and the public good that are central to the collective choices and accommodations being made around spectrum (and on which future innovations in design and use will rest). Per prior CSCW work on policy knots [26], they help us understand the interactions that occur at the intersection of design, practice, and policy. At the same time, wireless technologies (and the collaborative and social computing applications they support) are increasingly becoming central to CSCW work. Practically, maintaining a steady, stable, and accessible spectrum infrastructure is essential for creating a future of wireless and mobile devices, services, and applications. Furthermore, investigation of the dynamics of spectrum policy extends our understanding of how broader cultural processes interact with the imagination, practice, and design of technology. Better understanding of spectrum policy and the sociotechnical imaginaries that guide it can help enrich both the theoretical and practical reach of CSCW research.

REFERENCES

1. Baumer, E.P.S., Katz, S.J., Freeman, J., Adams, P., Gonzales, A.L., Pollak, J., Retelny, D., Niederdeppe, J., Olson, C.M., & Gay, G.K. Prescriptive persuasion and open-ended social awareness: expanding the design space of mobile health. In *Proc. CSCW 2012*, ACM Press (2012). 475-484
2. Chalmers, M., and Galani, A. Seamful interweaving: heterogeneity in the theory and design of interactive systems. In *Proc. DIS 2004*, ACM Press (2004). 243-252.
3. Comments of the American Association of State Highway & Transportation Officials. (2013). http://apps.fcc.gov/ecfs/document/view?id=7022418817
4. Comments of the Consumer Electronics Association (2013). http://apps.fcc.gov/ecfs/document/view?id=7022111851
5. Comments of Google Inc. and Microsoft Corp. (2013). http://apps.fcc.gov/ecfs/document/view?id=7022112070
6. Comments of Mobile Future (2013). http://apps.fcc.gov/ecfs/document/view?id=7022111797
7. Comments of Motorola Mobility LLC. (2013). http://apps.fcc.gov/ecfs/document/view?id=7022418844
8. Comments of the National Association of Broadcasters (2013). http://apps.fcc.gov/ecfs/document/view?id=7022418770
9. Comments of Public Interest Spectrum Coalition (2013). http://apps.fcc.gov/ecfs/document/view?id=7022112381
10. Comments of Sprint Nextel Corporation (2013). http://apps.fcc.gov/ecfs/document/view?id=7022112071
11. Douglas, S. *Inventing American Broadcasting, 1899-1922.* Johns Hopkins University Press, 1987.
12. Dourish, P. & Bell, G. *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing.* The MIT Press, 2011.
13. Edwards, W.K., Newman, M.W., and Poole, E.S. The infrastructure problem in HCI. In *Proc. CHI 2010*, ACM Press (2002), 423-432.
14. Engstrom, A., Perry, M., and Juhlin, O. Amateur vision and recreation orientation: creating live video together. In *Proc. CSCW 2012*. ACM Press (2012), 651-660.
15. FCC. Connecting America: The National Broadband Plan. (2010). http://broadband.gov/plan/
16. FCC. Expanding the Economic and Innovation Opportunities of Spectrum through Incentive Auctions. (2012). http://www.fcc.gov/document/broadcast-television-spectrum-incentive-auction-nprm

17. FCC. Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band. (2013). http://www.fcc.gov/document/5-ghz-unlicensed-spectrum-unii
18. Foth, M., Choi, J.H., and Satchell, C. Urban Informatics. In *Proc. CSCW 2011*, ACM Press (2011). 1-8.
19. Fujimura, J. Scientists as Sociocultural Entrepreneurs. *Genetic Nature/Culture: Anthropology and Science Beyond the Two-culture Divide*. University of California Press, 2003.
20. Galperin, H. Beyond Interests, Ideas, and Technology: An Institutional Approach to Communication and Information Policy. *The Information Society 20,* 3 (2004), 159-168.
21. Gaver, W. Making spaces: how design workbooks work. In *Proc. CHI 2011*, ACM Press (2011), 1551-1560.
22. Genachowski, J. Winning the Global Bandwidth Race: Opportunities and Challenges for Mobile Broadband. (2012). http://www.fcc.gov/document/chairman-genachowski-winning-global-bandwidth-race
23. Harmon, E. and Mazmanian, M. Stories of the Smartphone in everyday discourse: conflict, tension & instability. In *Proc. CHI 2013*, ACM Press (2013), 1051-1060.
24. Horwitz, R.B. Broadcast reform revisited: Reverend Everett C. Parker and the "standing" case (office of communication of the United church of Christ v. Federal Communications Commission). *The Communication Review 2*, 3 (1997), 311-348.
25. Horwitz, R.B. *The Irony of Regulatory Reform: The Deregulation of American Telecommunications.* Oxford University Press, 1989.
26. Jackson, S.J., Gillespie, T., and Payette, S. The Policy Knot: Re-integrating Policy, Practice and Design in CSCW Studies of Social Computing. In *Proc. CSCW 2014*, ACM Press (2014). 588-602.
27. Jackson, S.J., Steinhardt, S.B., and Buyuktur, A. Why CSCW Needs Science Policy (and Vice Versa). In *Proc. CSCW 2013*, ACM Press (2013). 1113-1124.
28. Jasanoff, S. and Kim, S.H. Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva 47*, 2 (2009), 119-146.
29. Kim, Sunyoung, Mankoff, J., and Paulos, E. Sensr: evaluating a flexible framework for authoring mobile data-collection tools for citizen science. In *Proc. CSCW 2013*, ACM Press (2013). 1453-1462.
30. Lakoff, G., and Johnson, M. *Metaphors We Live By*. University of Chicago Press, 1980.
31. Lim, Y.K., Stolterman, E., and Tenenberg, J. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM ToCHI 15,* 2 (2008).
32. Lindtner, S., Anderson, K., and Dourish, P. Cultural appropriation: Information technologies as sites of transnational imagination. In *Proc. CSCW 2012*, ACM Press (2012), 77-86.
33. Monteiro, E., Pollock, N., Hanseth, O., and Williams, R. From Artefacts to Infrastructures. *Computer Supported Cooperative Work* 22 (2013), 575-607.
34. Osenga, K. The Internet is not a Super Highway: Using Metaphors to Communicate Information and Communications Policy. *Journal of Information Policy* 3 (2013).
35. Peha, J. M. Sharing Spectrum Through Spectrum Policy Reform and Cognitive Radio. *Proceedings of the IEEE* 97, 4(2009), 708-719.
36. Powell, W.W. and DiMaggio, P.J. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organization Fields. *The New Institutionalism in Organizational Analysis.* University of Chicago Press, 1991.
37. Powell, W.W. and DiMaggio, P.J. Introduction. *The New Institutionalism in Organizational Analysis.* University of Chicago Press, 1991.
38. President's Council of Advisors on Science and Technology. *Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth.* (2012).
39. Rhodes, R.A.W. and Marsh, D. New directions in the study of policy networks. *European Journal of Political Research 21*, 1-2 (1992), 181-205.
40. Sabatier, P. An Advocacy Coalition Framework of Policy Change and the Role of Policy-Oriented Learning Therein. *Policy Sciences 21,* 2-3 (1988), 129-168.
41. Sengers, P., Boehner, K., David, S., & Kaye, J.J. Reflective Design. In *Proc. CC 2005*. ACM Press (2005), 49-58.
42. Sengers, P. and Gaver, B. Staying open to interpretation: engaging multiple meanings in design and evaluation. In *Proc. DIS 2006*, ACM Press (2006), 99-108.
43. Taylor, C. *Modern Social Imaginaries.* Duke University Press, 2004.
44. The White House. Presidential Memorandum: Unleashing the Wireless Broadband Revolution. (2010). http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution